Chapter 2. Study Methods and Approach

Field Surveys

Field surveys consisted of two aerial reconnaissance low-altitude flights in fall 1997, a field reconnaissance survey over several days in late fall 1997, and channel cross section topographic and bathymetric surveys conducted over three separate weeks in winter/spring 1998.

Aerial Reconnaissance Flights

Low-altitude aerial reconnaissance flights of the San Joaquin River were conducted in fall 1997 (September 17 and October 29) in a 5-seat, high-wing plane with a removable window panel to improve visibility and reduce photographic distortion.

During both flights, vegetation pattern and dominant species were observed throughout the 150-mile study area, as well as between the Delta and the Merced River for comparison. Also during the flight, channel planform and important geomorphic and hydrologic features were observed and recorded.

Color slides and prints were taken between the Tuolumne River and Friant Dam, some of which appear as aerial oblique photographs in Appendix B, Plates 1 to 22 and 81 to 86. A number of photographs were taken to illustrate the geomorphic characteristics of the river and to document the erosional and depositional characteristics of the river and the sloughs as well as the bypasses of the flood control system. Aerial oblique photographs were also used as additional ground-truthing exhibits to compare to plan view aerial photomaps used to record vegetation cover type in the preceding study, *Historical Riparian Habitat Conditions of the San Joaquin River* (Jones & Stokes Associates 1998). Photograph numbers, recorded as waypoints, were established with a hand-held global positioning satellite (GPS) receiver and later plotted on a base map of the study area to confirm the location of the image recorded (map in Appendix A).

Ground Level Surveys

A two-person field reconnaissance survey was conducted by the study ecologist and geomorphologist over several days in late fall 1997 (October 29–November 2). Each site recorded with a waypoint during aerial surveys was surveyed on foot. As much as possible, travel routes between waypoints were driven on levee roads to observe additional areas of the river (over 800 miles were traveled by vehicle). Vegetation structure, condition, dominant species, and relation of species to channel geometry were observed throughout the 150-mile study area, and apparent limiting factors were noted where possible. Of particular interest at field sites was the presence, recent mortality, or absence of seedlings and saplings of riparian species, which are important vegetation features not visible from aerial photographs.

Ground-level photographs, which appear in Appendix B, were also used for ground truthing plan view aerial photomaps. Photograph numbers were also recorded in association with GPS unit waypoints and plotted on a base map of the study area (map of waypoints, Appendix A).

During the course of the ground-level surveys, nine bulk sediment samples were collected for subsequent laboratory determination of their gradations and four Wolman pebble counts (Wolman 1954) were made to establish surface sediment gradations of the coarser bed material in the upper reaches of the river. Bulk sediment samples were collected on bars in the San Joaquin River at RM 133, 174, 197, 199, 215, 223.5, and 229 and in the Eastside Bypass at Bravel Slough and immediately downstream of the Sand Slough Control Structure. Wolman pebble counts were made on bars in the San Joaquin River at RM 240, 247, 255, and 266.8.

Cross-Section Surveys

Based on the aerial and ground-level reconnaissance and subsequent evaluation of the CDC 1914 survey of the San Joaquin River, fourteen cross sections were selected to represent the geomorphic conditions within the study reach (Appendix A). These cross sections (located between RM 117.8 and RM 243.2), with the exception of cross section #25 (RM 211), were subsequently resurveyed in March and April 1998. Nine cross sections between RM 234.4 and RM 266.6, originally surveyed by the USBR in 1939 and subsequently resurveyed in 1996 by Cain (1997), were used to evaluate changes in the reach upstream of the CDC survey.

Twelve of the 1914 cross sections were located and scheduled for resurveying. Data were collected for 11 of the cross sections during three field visits made during the weeks of February 17, March 10, and March 25, 1998. One cross section (#25) was inaccessible at the time of survey. The locations of the 1914 cross sections were cross-referenced to current UTM coordinates using section corners identified in the 1914 plan sheets. Alignments of the selected 1914 cross sections were digitized for guidance in locating and resurveying the 1914 alignments during field data collection activities.

Field data were collected using GPS survey methods. Cross-section data were collected using land-based GPS surveying combined with the collection of bathymetric data using an Innerspace depth sounder. Vegetation observations were noted in conjunction with the ground points. Dual-frequency, real-time kinematic surveying methods were used, with horizontal and vertical control brought in from available survey monumentation. Where available, first-order control data were referenced. Control data were obtained both from the National Geodetic Survey (NGS) and from information supplied by DWR. It should be noted that the distance between cross sections and the budget for field data collection did not allow for development of a complete survey control network. Consequently, the cross sections are not connected in a common network and the cross section comparisons could be influenced by the accuracy of the referenced control points. Although these factors could affect the absolute values of the surveys, it is not anticipated that they would introduce dramatic differences in interpretation of the changes between 1914 and the present.

Analytical Methods

Hydrology

The hydrology of the San Joaquin River within the study reach is extremely complex. Sources of data used to develop information for this study include previous peak flow analyses conducted by the Corps (U.S. Army Corps of Engineers 1993, 1997), Cain (1997), and the Bay Institute (1997). Although a relatively large number of gaging stations are located within the study reach, the gages are maintained by a number of different agencies (DWR, USBR, and USGS), and the periods of gage operation and the lengths of published records are highly variable. Another complication is introduced by the development of the water resources projects in the basin, construction of the flood control system, and the importation of water from the Delta via the Delta-Mendota canal. For the purposes of determining peak flow frequency information for the pre-and post-Friant periods (i.e., pre- and post-1948), the annual peak flow information for the Friant gage (11251000) and the Fremont Ford gage (11256500) was evaluated by the standard WRC Bulletin 17B procedure for the available records in the two periods. A peak flow frequency analysis was also conducted for the Mendota gage (11254000) and the Dos Palos gage (11256000) for the periods from 1941 to 1954. The results of the analyses are presented in Chapter 3.

Flow-duration curves were developed from the mean daily flows for nine gaging stations located on the San Joaquin River and Mud and Salt Sloughs. The gage records were subdivided into pre-and post-Friant periods when possible. Flow-duration curves were developed for the annual flow record and for the April–May period because of its significance with respect to vegetation establishment. The results are presented in Chapter 3.

Hydraulics

Hydraulic analyses with one-dimensional hydraulic models (HEC-2 or HEC-RAS) to determine channel capacity and discharge requirements to generate overbank flows were conducted for those reaches of the San Joaquin River that were covered by the models (see "Prior Investigations and Studies" in Chapter 1). In addition, a normal-depth analysis was conducted with the HEC-RAS model for the 1914 cross sections and the 1998 resurveyed cross sections.

Existing hydraulic models for the San Joaquin River within the study reach were evaluated to identify data that could be used in this study. The data, which came from a variety of sources, were dated from 1913 to 1998 and were from locations throughout the study reach. Although difficulties in accurately connecting the data locations to a common reference geographic datum narrowed the data field significantly, several useful data sets were identified.

Existing hydraulic data collected includes maps, cross-section plots, water surface elevations, thalweg profiles, water surface slopes, bridge soundings, and full or partial HEC-2 models. These data were gathered from a variety of sources, including the USGS, the Corps, Caltrans, USBR, Federal Emergency Management Agency (FEMA), California Department of Water Resources (DWR), and Cain (1997).

One of the most valuable sets of data consists of maps and cross sections of the San Joaquin River completed by the CDC in 1914 (see "Prior Investigations and Studies" in Chapter 1). Cross sections are from locations throughout the study reach and provide an excellent opportunity for resurveying and evaluation of channel morphology over the past century. These cross sections have becoming the primary focus of the geomorphologic study, although other existing data have also proven useful.

Fourteen 1914 cross sections were chosen for analysis; these cross sections are from locations between the Hills Ferry Bridge crossing (RM 118.2) and the Highway 99 bridge crossing (RM 255.5). Thirteen of these were actually used in the study and are listed in Table 2.1 and shown on the map in Appendix A. Two existing cross sections from locations near two of the 1914 sections were identified in recent HEC-2 data sets. One of the data sets is an executable model used for a floodplain study for the City of Firebaugh (FEMA 1995), while the other is from a location upstream of Gravely Ford and contains only cross sections in HEC-2 format (U.S. Army Corps of Engineers circa 1980-1985). Three other existing executable HEC-2 models, in addition to the Firebaugh model, were run to provide hydraulic information for portions of the study reach. These were: Bear Creek, used for a levee deauthorization study (DWR 1997); Highway 99, used for a riparian vegetation study (DWR 1996); and Fresno, used for a flood insurance study (FEMA 1980). Bridge cross sections provided by Caltrans and information from Cain (1997) were also used in the study.

Using plotted water-surface elevations for a range of flow events proved to be the most useful method of evaluating past and present channel conditions because of the limited data available. Normal depth calculations in HEC-RAS were used to evaluate single cross sections. Existing HEC-2 models were imported to HEC-RAS and provided hydraulic data on additional sections of the river. Water-surface elevations were computed up to channel capacity for the 1914 cross sections and maximum operating levels (design discharges) for the 1998 cross sections and existing HEC-2 models.

Basic input requirements for HEC-RAS are channel cross sections, overbank locations, distances between cross sections, roughness coefficients, discharge, and a starting boundary condition (e.g., stage, energy slope). The 1914 and 1998 cross sections were digitized and imported as separate geometries to HEC-RAS. Overbank locations were estimated from the 1914 maps and plots and 1998 field observations. The single cross sections were copied with an arbitrary distance of 10 feet between sections to form individual channel geometries. Manning's roughness coefficients of 0.035 and 0.07 were chosen for the channel and overbanks, respectively, and the slope of the energy grade line was used as a starting boundary condition. Geometries, Manning's roughness coefficients, and starting boundary conditions were not altered in the existing HEC-2 models unless necessary (i.e., when models were cut or shortened for simplicity, or different discharges were used). The single cross section taken from the collection of cross sections in HEC-2 format (U.S. Army Corps of Engineers circa 1980-1985) was imported and modeled in the same manner as the 1914 and 1998 sections.

The energy slope of the channel has a significant impact on the outcome of the model and thus should be estimated as accurately as possible. Since this slope is rarely available, the slope of the water surface is often used to approximate it. The slope of the energy grade line, or water surface, in the San Joaquin River has undoubtedly changed over time so it was important to be consistent in its estimation. The water-surface slopes for the single cross sections were estimated by dividing the difference in water-surface elevation between the cross section of interest and the next downstream section by the channel distance between them. This calculation was based on water-surface elevations periodically noted on the cross section plots from the 1914 data and surveyed water-surface elevations at each cross section from the 1998 data. This method obviously ignores the effects of diversions or other control structures at some sections, particularly for the 1998 data. The estimates, however, still appear reasonable and tend to agree with trends noted by Cain (1997) in the upper portion of the study reach. Water surface slopes for the two HEC-2 cross sections used for comparison with the 1914 data were obtained from a previous run of the model for Firebaugh and from Cain (1997) for the Corps cross section upstream of Gravelly Ford. Water surface slopes ranged from 0.0001 to 0.0006 and are shown in Table 2.1.

Geomorphology and Sedimentology

Geomorphic data for the study reach of the San Joaquin River were obtained from the 1914 survey of the river and its flood basins and floodplains. From the 85 cross sections surveyed between RM 117.8 and RM 243, morphometric data were obtained. These included the thalweg (bed) and top-of-bank profiles, channel widths and depths at bankfull stage, and the width-depth ratio. Resurveys of the selected 1914 cross sections enabled changes in channel morphometry to be evaluated. Morphometric data from 1938 to 1996 for the reach of river between Herndon (RM 243) and Friant Dam (RM 267) were developed by Cain (1997) and were used in this investigation to evaluate changes over time in that reach.

No sediment transport analyses were conducted for this investigation. However, field sampling of the bed and bar sediments and visual observation of the study area enable some generalizations about existing sediment transport and deposition. Cain's (1997) sediment budget for the upper reaches of the river provides a reasonable basis for evaluating the effects of aggregate mining. Reports of sediment accumulation in the system (U.S. Army Corps of Engineers 1993) and personal observations of sediment accumulation rates and removal volumes (Hill pers. comm.) also provided useful information on the sediment flux in the river and bypasses. To conduct a sediment transport analysis for the study reach, it will be necessary first to develop an integrated hydraulic model of the study reach, and second to develop a better understanding of the hydrologic changes in the system, especially in the essentially sand-bed reaches downstream of Gravelly Ford.

Characteristics of Riparian Vegetation

Riparian vegetation consists of the plant community within a river channel and on the channel margins. Plant species that make up the riparian community tend to be adapted to the changing physical environment that characterizes a fluvial system. For example, Simon and Hupp (1987) demonstrated that specific geomorphic processes could be associated with riparian species in rapidly adjusting channels in Tennessee. The formation of fluvial landforms (bars, floodplains, and terraces) can be related to distinctive hydrogeomorphic processes (flow duration and flood frequency) that appear to be largely independent of vegetation (Hupp and Osterkamp 1985). Once established, however, vegetation is an integral part of the fluvial system. Riparian vegetation has the potential to affect sediment deposition, channel stability, and channel dynamics.

Vegetation and Sedimentation Processes

Many riparian species are able to tolerate burial by sediment (Hook and Brown 1973; Harvey and Spitz 1986; Harvey, Pitlick, and Laird 1987; Simon and Hupp 1987). However, this tolerance varies among species and appears to be dependent on the rate of sedimentation, the type of sediment deposited, and the age of the individual tree within a species (Harvey and Spitz 1986). Because of increased hydraulic roughness, riparian species tend to induce sediment deposition in both channel and channel margin environments (Harvey and Watson 1987). High rates of overbank sedimentation tend to be associated with large floods (Sigafoos 1964, Kesel et al. 1974, Watson et al. 1986). However, over longer periods of time, sedimentation rates in the floodplain tend to be low (i.e., 1–3 mm/yr. [Kesel et al. 1974]). Rates are highest on the channel margin, and they decrease exponentially away from the channel (Allen 1985, Bridge and Leeder 1979). Significant reworking of overbank sediments can occur during a single flood or in subsequent floods (Sigafoos 1964). The rate of sedimentation on a floodplain is governed by the elevation of the floodplain with respect to the water-surface elevation of floods. If an area is inundated frequently, the rate of deposition will be high. As the elevation increases as a result of sedimentation, larger and less frequent floods are required to inundate the surface and sedimentation rates will, therefore, be lower (Wolman and Leopold 1957). Ritter (1978) has argued that in meandering streams, the rate of sediment accumulation on the floodplain must be ultimately controlled by the rate of lateral migration of the channel.

Vegetation and Channel Stability

The role that riparian vegetation plays in determining channel stability is less clearly understood. Zimmerman et al. (1967) concluded that vegetation has an effect on channel form in small streams but only marginal effects in larger streams. Shifflett (1973) concluded that in rivers with high banks (10-15 ft), vegetation has little effect on channel stability, and he concluded that large trees that had been eroded from the top bank could induce further bank erosion, a point that was also made by Brice (1977). Towl (1935) and Brice (1974, 1977) attributed reduced sinuosity of the Missouri, White, and Sacramento Rivers, respectively, to a reduction in riparian vegetation. Brice (1977) concluded from the morphology of meander cutoffs on the Sacramento River that the river was more sinuous and stable prior to removal of riparian vegetation. Smith (1976) and Odgaard (1987) concluded that riparian vegetation in relatively shallow rivers significantly reduced the rates of bank erosion. In contrast, Nanson and Hickin (1986) demonstrated that riparian vegetation had very little effect in reducing bank erosion, probably because they were studying larger rivers. There is little doubt that riparian vegetation will reduce or prevent erosion on the floodplain (Brice 1977).

Evaluation of Vegetation Condition and Trends

Sources of Information

Information on soils and groundwater conditions that may affect riparian vegetation were obtained from published reports, surveys, and maps. Surface soil salinity was also observed in the field in the form of salt encrustation and efflorescence, often associated with the presence of halophytic (salt-tolerant) plants (e.g., *Sueda*, *Distichlis*) or bare, moist ground. Hydrology patterns for each subreach were obtained from previous reports and electronic gage databases (see Chapter 3) and were observed in the field in fall and winter 1997 (e.g., presence or absence of flow) and spring 1998 (moderate to high flood flow). Management of flood control dams and weirs is contained in Corps reports describing design flows and routine operating criteria, supplemented by additional information from the LSJLD. Geomorphic and topographic information is described elsewhere in this report. Recent effects of herbivory and vegetation scour or removal were observed directly in the field (e.g., beaver sign, burn sites, recent grading activity, vegetation displaced or damaged by high-velocity flows), as were indicators of recent riparian colonization (seedlings, saplings, or young growth in linear rows or even-aged stands).

The only previous source of site-specific descriptions of existing riparian vegetation is contained in Cain (1997), which covers subreach 1. Otherwise, data concerning existing and historical spatial distribution of riparian vegetation types in the study area were obtained from the results of a literature review and maps from aerial photographs contained in *Historical Riparian Habitat Conditions of the San Joaquin River* (Jones & Stokes 1998). Ground truthing of vegetation maps was primarily performed by comparing 1993 photomaps to 1997 ground level and low-altitude oblique aerial photographs of the entire study area, with partial field verification and comparison to other survey notes.

Qualitative observations of vegetation composition and structure in relation to elevation above the low-flow channel were made during the field surveys. Some quantitative verification of vegetation along elevational gradients was provided by notes recorded during the 1998 cross section topographic surveys.

Analytical Assumptions: Field Indicators

The January 1997 flood event was the flood of record on the San Joaquin River since the construction of Friant Dam (approximately 60,000 cfs peak flow at Friant gage). Therefore, disturbance cycles of scour and deposition affecting riparian vegetation are assumed to have been near peak levels during field surveys in the aftermath of winter flooding and high flows throughout the San Joaquin River study area. Hydrology conditions (base flow, soil moisture, and shallow groundwater) during the October–November surveys are assumed to be nearer the wet end of the spectrum for cycles of drought and wet years. The combination of recent scour and deposition, coupled with prolonged spring base flow and higher than average water tables, is assumed to represent favorable conditions for seed dispersal, recruitment, and survival of riparian seedlings during the past 2 to 3 years. The absence of recruitment at some sites is assumed to indicate a more persistent limitation of regeneration potential in particular reaches.

Direct vegetation removal (mechanical, herbicide, or controlled burn) within the San Joaquin River channel was observed in only two areas: a burn site south of Firebaugh (possibly from a wildfire), and where sand in the active channel is being removed at several sites over a large portion of subreach 2. The last major channel vegetation–clearing project was performed between Fresno and Gravelly Ford during the 1960s by the Corps in association with completion of the flood control project. Snagging and clearing proposed in 1990 between Mendota and Merced River was never implemented because of lack of adequate funding and environmental permitting issues. Therefore, the establishment and development of riparian vegetation is probably limited by physical and management factors rather than vegetation removal.

Sites dominated by old-growth trees and punctuated by senescent and downed trees, with an absence of riparian understory shrubs, saplings, and herbaceous cover types, are assumed to represent relict stands of riparian habitat lacking regeneration potential under existing conditions. Sites dominated by seedlings, saplings, or young willow scrub and lacking mid-successional and mature forest types even at higher floodplain elevations are assumed to have experienced recent or frequent cycles of disturbance or removal. This condition is typically associated with other signs of scour and deposition in the bed and occasionally by lateral retreat of channel banks as well. Sites where low sand and gravel bars in the active channel are dominated by mature vegetation associations (e.g., alder-buttonwillow-ash or mixed riparian forest) are assumed to lack the normal frequency and magnitude of disturbance cycles (scouring flows) characteristic of the active channel, particularly in the aftermath of the 1995 and 1997 events.

Competition with exotic (non-native) trees and shrubs was assumed to limit native riparian species at locations where exotics were observed in large, monotypic stands on shorelines and low sites within the channel that would otherwise appear capable of supporting natural riparian vegetation. Displacement of riparian vegetation by agricultural expansion (e.g., new vineyards) or encroachment of urban uses (e.g., golf courses, gravel pits) was assumed to have occurred at locations where the land use appeared to be a recent change (new construction or grading activity, new plantings) and was present at comparable elevations and in the vicinity of undisturbed stands of existing riparian vegetation. This field observation was typically made on lower alluvial surfaces because the upper floodplain and terraces (abandoned floodplain) along the San Joaquin River were thoroughly converted to agricultural uses, and extensive local levee systems were already in place, by the early 20th century (see 1914 maps and cross sections, Appendices C and D). An exception is mining of gravel from older terrace deposits in subreach 1.

Analytical Assumptions: Data on Physical Environment

Areas with average groundwater depth contours within 10 feet of the surface shown in previous studies are assumed to be capable of supporting riparian phreatophytic plants once they establish if there are not other limiting factors. Generalized maps of groundwater indicating mineral solute concentrations exceeding 2,500 microSiemens per centimeter (electrical conductivity [EC]) for sodium and 2 parts per million (ppm) for boron are assumed to represent areas potentially lethal to seedlings of riparian plants where groundwater is near the surface and may not be diluted by relatively higher-quality surface water available to plants during the growing season.

Surface hydrology in reaches interrupted by long periods of no flow in average years during the growing season and apparently lacking shallow groundwater under coarse-textured substrate is assumed to limit colonization and survival of riparian vegetation. However, unknown local variations in site-specific surface and groundwater conditions, such as perched water tables over clay lenses or local agricultural irrigation tailwater or seepage from adjacent canals and irrigated fields in close proximity to the channel, may be more favorable to riparian plants. No flow conditions are common in subreach 2 and portions of subreaches 4A and 4B.

Surveyed cross sections for which stage-discharge frequency curves were developed for this study indicate a significant reduction in the extent and duration of inundation of historic floodplain surfaces. A large proportion of existing riparian vegetation types (valley oak woodland, mixed riparian forest, cottonwood forest) occurs on middle and upper floodplain surfaces and in basins outside of levees. The absence of periodic inundation, siltation, and surface scarification and wetting associated with out-of-bank flow is assumed to represent conditions that favor gradual vegetation succession to age-dominant and more drought-tolerant community types over regeneration of willow scrub and cottonwood. An exception would be where lateral channel migration from bed incision and bank retreat may create new, lower floodplain surfaces more subject to periodic flooding, potentially favoring vegetation establishment.